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An Extended Vector Product Format Profile for Modeling and Simulation

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13. ABSTRACT *(Maximum 200 words)*

The Vector Product Format (VPF) has been advancing, through prototype development, the Defense Mapping Agency's (DMA) transition from paper products to geographic information system environments. Indeed, that was VPF's main intent. Lately, however, the DMA has recognized that the VPF prototypes have not been meeting the requirements of a particular group, the Modeling and Simulation (M&S) community. Through support from the Terrain Modeling Project Office and the Defense Modeling and Simulation Office, the Digital Mapping, Charting, and Geodesy Analysis Program (DMAP) has been tasked to extend VPF to satisfy M&S Requirements. What follows is DMAP's initial profile of the Extended VPF and its first prototype. While by no means a completed standard, the EVPF profile is described by DMAP as a promising VPF alternative for the M&S community.

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Contents

An Extended Vector Product Format (EVPF) Profile for Modeling and Simulation

1.0 Introduction

1.1 Products in the Vector Product Format (VPF), a georelational database format, have made great strides at effectively representing what was once a "paper only" environment. The Digital Nautical Chart (DNC), Vector Smart Map (VMap), and Tactical Terrain Data are but a few such databases currently under development which, when completed, should provide excellent digital substitutes for harbor, approach, coastal, and general charts, as well as various culture datasets. In fact, VPF's strength can be observed in its digital representation of charts. It allows the collapsing of a three-dimensional (3-D) environment into two-dimensional (2-D) thematic layers, under rigorous geometric and topological guidelines.

1.2 Unfortunately, for today's modeling and simulation (M&S) community, VPF's representation of an environment is deficient in several regards. The ability to represent culture, terrain, and models in three dimensions is an absolute necessity in most M&S scenarios. While VPF allows for storage of feature height information in various attributes, VPF and its application software VPFView are essentially two dimensional.

1.3 Rich attribution of features is also desirable to the M&S community to accurately portray models in 3-D. Extensive M&S requirements analyses [1,2] have proven VPF's inadequate attribution in most of its databases.

1.4 Finally, VPF's construction of logically separate thematic layers can pose problems, especially in the format's elimination of topology (connectivity) between coverages.

2.0 Spatial Dimensions

2.1 VPF's geometrical limits extend from zero-dimensional *nodes* to one-dimensional *edges* and two-dimensional *faces*. These are represented in VPF as *primitive* tables. To naturally extend VPF into three dimensions, an additional data structure has been proposed, the Triangulated Irregular Network (TIN).

2.2 Terrain has been shown to be effectively represented and utilized for analysis as a TIN, whereby terrain is represented as network of irregularly shaped triangles. A current literature search and discussions with M&S programs have shown that TINs have become a widely used structure and can be generated from elevation posts of regular spacing, e.g., Digital Terrain Elevation Data (DTED), a commonly used dataset in M&S.

2.3 The Digital Mapping, Charting, and Geodesy Analysis Program (DMAP) proposes to transform the DTED Level 2, 30-m post spacing, within Extended Vector Product Format (EVPF) as a TIN structure. Since there are multiple representations of TINs in relational

databases, investigations are currently underway to determine the representation best suited for VPF's geometric structure. The anticipated result is a new primitive beyond VPF's current limit of *face*, together with a corresponding feature table to store appropriate attribution. Moreover, TIN and additional formats of elevation data will comprise a single VPF coverage.

2.4 Appendix B presents DMAP's preliminary observations on the relative difficulty of integrating TINs into VPF. Of the three presented storage formats, DMAP proposes to use the triangle-based data structure. Although new file definitions must be created for this structure, it shows considerable promise in terms of storage requirements, access speed for viewing software, and simplicity.

2.5 With respect to TIN generation, many algorithms exist. Since regular grid data will be input, the current plan is to use the generation algorithm of the commercial geographic information system ARC/INFO, which can complete such transformations with minimal input from the user. For testing purposes, DMAP has successfully generated a TIN from VPF contour lines in Urban Vector Smart Map. The intent is now to apply this concept to a more realistic scenario, namely generating TINs from DTED 2.

3.0 Feature and Attribution Content

3.1 For an object to be modeled successfully, sufficient attribution must be supplied. The required amount of attribution, of course, depends on those programs modeling the object. Once sufficient and appropriate attribution is available in a given form, successful modeling can take place within a program's own system/simulation.

3.2 To that end, DMAP has based the feature and attribute content on the most up-to-date requirements analyses of 38 Army programs and 110 Navy/Marine Corps programs involved with M&S [1,2]. Additionally, feature and attribute content of the prototype VPF product will contain features and attributes made available in all current VPF prototypes (DNC, Digital Topographic Data, World Vector Shoreline, VMap 0, VMap 1, VMap 2, UVMap), with redundant features eliminated.

3.3 Additionally, Digital Feature Analysis Data (DFAD), a product which is currently used by many M&S programs as a source of cultural information, will be analyzed and incorporated into the extended VPF prototype. (As an aside note, much of DFAD has been integrated into VMap Level 1.) Compared with several current VPF products, DFAD seems limited in feature content. However, its rich attribution satisfies many M&S requirements. No difficulties are anticipated with incorporating such attribution.

3.4 The following section introduces DMAP's initial coverage and feature profile separated into logical thematic groupings that will evolve into VPF thematic coverages. All available Feature and Attribute Coding Catalog (FACC) codes are represented, and those with no code are not yet available in FACC. Once codes are established, all features should be stored in VPF's relational format with equal ease.

4.0 Proposed EVPF Profile

4.1 Appendix C describes required features, grouped into the proposed 12 EVPF coverages *Aeronautical Information, Beach, Data Quality, Demarcation, Elevation, Hydrography, Industry, Physical Geography, Population, Transportation, Utilities,* and *Vegetation*, with some temporary subheadings for clarity. References to geometry (area, line, and point) are minimized so as to avoid future conflicts with scale. Blanks indicate FACC codes to be developed, and "*" indicates "not a currently identified requirement." DMAP recommends the latter features for inclusion on the basis of future requirement indications. Approximately 20 new FACC features are proposed here, and many other codes required by Navy and Army M&S programs exist in the FACC, but not in any current VPF product.

4.2 Attribution is "to be determined" and will fulfill all requirements without causing multiple representation of entities, as stipulated by VPF. New attribution, including physical measurements relating to infrared properties, emissive properties, reflective properties, and thermal conductivity, will be integrated with standard attribution to satisfy remaining requirements. Some new attribution codes will obviously be needed to supplement the FACC, which may present future technical challenges. Once completed, however, the resulting profile of features and attributes should surpass content of any given VPF product to date.

5.0 Thematic Coverages

5.1 VPF allows similar data objects to be grouped into coverages for the purpose of defining topology. VPF stipulates that topology, by definition, does not extend between coverages. A simple example illustrates the impact of such a restriction: If roads are in coverage Transportation and bridges are in coverage Hydrography, no information about connectedness between road and bridge can be inferred. Careful requirements analyses and mission requirements have been studied to determine coverage content for the existing VPF products.

5.2 Coverages must exist not only for topological reasons but for topography preservation as well. For example, a lake area exists in a land area. Since both area features cannot geometrically exist within a single VPF coverage, separate coverages are required.

5.3 Perhaps the most ambitious (and time consuming) extension to VPF would be to "connect" information between coverages. Clearly, separate coverages reinforce logical separation of data and data manageability. On the other hand, connection between coverages could allow for more enhanced operations, such as thinning, an important concept in M&S. DFAD allows for a way of "stacking" features, thereby in a sense, introducing topography information into the 2-D representations of features. EVPF should have similar capability. However, for the initial prototype, the separate, individually connected coverages of section 4.0 will be the extent of connectedness.

6.0 Software Considerations

6.1 In creating a preliminary prototypical EVPF database for M&S, software must be developed not only to generate TINs, as discussed in Section 2.0, but also to form tables of features from existing VPF products. Since the current products do not normally cover the same geographic area, some data must also be simulated. Software tools are needed to generate VPF tables in all cases.

6.2 A collection of "C" routines is currently being written to manipulate VPF tables. These functions allow the user to read, write, display, delete, and copy elements or rows in VPF tables, thereby allowing DMAP to prototype an M&S VPF prototype which conforms to the basic tenets of the VPF standard and the extensions. Once software engineering is complete, DMAP will have the mechanism to merge diverse database coverage information into the M&S prototype.

6.3 In particular, VPF software tools (collectively called VPFTool), previously used to create a point coverage for the Naval Search and Rescue routine, are being refined and extended to develop these capabilities. Recent additions to VPFTool include:

- *Attribute table merging routines.* A source table row is mapped to a new attribute table, transferring any identical column entries and providing the appropriate null values for columns not found in the source row.

- *Database creation tools.* A set of functions that build the required database header, geographic extent, and library header tables using a template file, sensible default values, and a limited amount of user input, making the construction of a skeleton EVPF database structure quick and easy to accomplish.

- *Point and text feature primitive constructors.* These routines provide a method of sorting text and entity node data by geographic extent and tile, providing a means of migrating existing data to a new database. These functions also provide a way to store selected VPF data in VPF format using the additional database creation functions outlined above. No anticipated difficulties are expected for the line and area primitives.

6.4 Algorithms for constructing the initial EVPF prototype have also been developed. For example, the steps for migrating a coverage to a new database are defined as follows:

1) Create a set of extents, tiled or untiled, that define the new library.

2) Create a new attribute table in which to store the existing coverage attribute data.

3) Transfer the existing data. The software will map the existing attribute rows to the new table and create a table in which to insert any associated primitives that fall within the extents of the new library. If that table already exists, the primitives are appended to that table.

6.5 For displaying the prototype extended VPF, a 3-D software viewing package, PolyView version 3.1, will be used. This public domain package shall enable DMAP to display a terrain skin along with 3-D objects and have a "fly-through" capability. The relationship among the 3-D objects cannot be varied, but sequential images can be used to simulate the relative motion of objects. Documentation unfortunately extends only through version 2.0, so some difficulty is expected to be encountered.

7.0 Issues for Future Consideration

7.1 Unlimited extensions to VPF could be performed. As mentioned in an earlier section, connections between coverages has yet to be resolved.

7.2 Another issue is that of the temporal data. Many features have attribution that extends well beyond that of a "single instance in time." Forward Looking Infrared, for instance, is highly sensitive to time. Efficiently storing such information in a relational database is certainly a topic of concern which lies beyond the scope of the problem at hand.

7.3 Resolution and level of detail are additional topics of interest in M&S. VPF fixes a scale at product development time. WVS, for example, has five separate libraries corresponding to five distinct scales. A hierarchical TIN data structure has been developed to address the concept of storing terrain at various scales (see Appendix B for a brief introduction). Representing scaled data in EVPF, to the benefit of the M&S community, could very well be a separate project unto itself.

8.0 Conclusions

8.1 Results to date have been substantial and promising. The major extension to VPF, the incorporation of 3-D terrain data, has been carefully planned: The popular TIN data structure has been selected, the method of storage of TINs has been selected, and research into TIN generation from regular grids such as DTED is underway. Moreover, all current and future M&S requirements have been compiled. Software is currently being designed, and attempts at using completed software have been successful.

8.2 Anticipated difficulties are in the form of display software, and modeling 3-D objects described by the attribution of EVPF. Limited geographic extent of existing VPF products may pose a problem to EVPF prototype generation, particularly since each product has it's own unique extent.

9.0 Acknowledgments

9.1 This effort was sponsored by the Defense Mapping Agency's Terrain Modeling Program Office and the Defense Modeling and Simulation Office, under Program Element 630603832D, with Mr. Jerry Lenczowski as program manager.

10.0 References

1. Shaw, K. et al., *A Comprehensive Analysis of Navy and Marine Corps Digital Mapping, Charting, and Geodesy Requirements for Modeling and Simulation*, NRL/FR/7441--93-9435, 9 January 1995.

2. Othling, W. and L. Speir, *Analysis of Digital Topographic Data Requirements for selected Army Models/Simulations*, Contract No. DACA 76-90-0002, Delivery Order No. 6, Task 1, prepared for U.S. Army Topographic Engineering Center, Ft. Belvoir, VA, 22060, 31 January 1993.

Appendix A. Acronym List.

2-D	Two Dimensional
3-D	Three Dimensional
ARC/INFO	commercial geographic information system
DFAD	Digital Feature Analysis Data
DMAP	Digital Mapping, Charting, and Geodesy Analysis Program
DNC	Digital Nautical Chart
DTED	Digital Terrain Elevation Data
EVPF	Extended Vector Product Format
FACC	Feature and Attribute Coding Catalog
M&S	Modeling and Simulation
TIN	Triangulated Irregular Network
VMap	Vector Smart Map
VPF	Vector Product Format
VPFTool	VPF software tools
VPFView	VPF viewing software
WVS	World Vector Shoreline

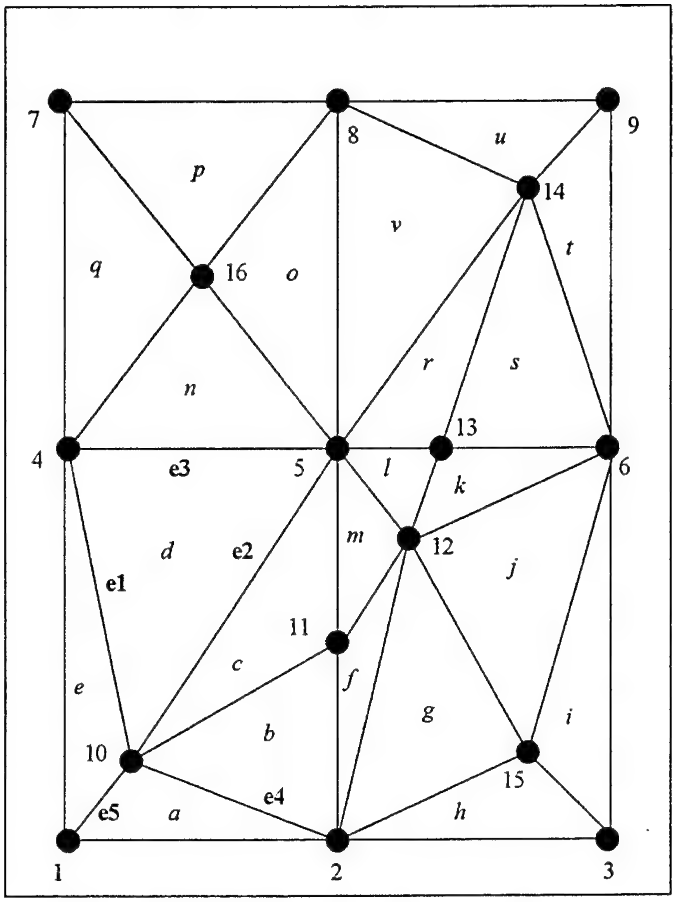
Appendix B. TIN Data Structures.

DATA STRUCTURE FOR TINs

PRELIMINARY THOUGHTS

- Storing TINs by adding a third dimension to VPF's vertices
- Storing TINs using a triangle-based data structure
- Storing TINs using a vertex-based data structure

VPF-Based Data Structure



Sample Triangular Network
$\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3, \ldots$ edges
1, 2, 3, … vertices
a, *b*, *c*, … triangles

Connected Node Table:

ID	x	y	z
1	x_1	y_1	z_1
2	x_2	y_2	z_2
. . .	. . .	. . .	. . .

Edge Table (level 3 - LFT_ID not included):

ID	start_node	end_node	right_edge	left_edge	right_face	left_face	coordinates
e_1	4	10	e_5	e_3	e	d	$x_1y_1z_1$ $x_2y_2z_2$
...	...	...	...	...	...	...	...

Face Table (a face is any triangle that does not contain an edge inside - AFT_ID not included):

ID	Ring_pointer
...	...
d	9
...	...

Ring Table:

ID	Face	Starting_edge
...	...	...
9	d	e_1
...	...	...

Storage Requirement = (54N - 18B - 49) storage units

- N = number of TIN vertices
- B = number of TIN vertices that belong to the convex hull
- storage unit = amount of storage needed to store either a pointer or one coordinate

Basic Queries:

- Point Location: requires reading several VPF tables
- Edge Neighbor finding: needs only the edge table
- Vertex Neighbor finding: difficult to perform

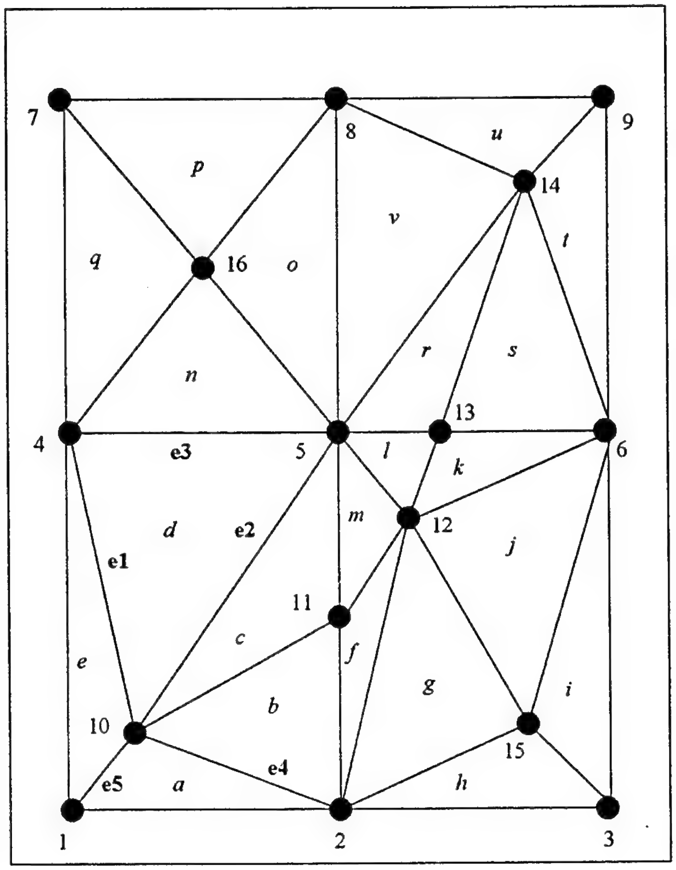
Advantages:

- Visualization software available?
- Minimum change to VPF
- Allows for area, line, and point features

Disadvantages:

- Storage requirement
- Complex data structure that was not meant for TINs

Triangle-Based Data Structure



Connected Node Table:

ID	x	y	z
1	x_1	y_1	z_1
2	x_2	y_2	z_2
...	...	...	...

Face Table (stores triangles):

	Vertices:			Adjacent Triangles:		
ID	V_1	V_2	V_3	T_1	T_2	T_3
a	1	2	10	null	b	e
b	2	11	10	f	c	a
...	...	...	...	...	...	...

Storage requirement = 18N - 7B - 14 storage units

Basic Queries:

- Point Location: simpler than VPF data structure
- Edge Neighbor finding: simpler than VPF data structure
- Vertex Neighbor finding: simpler than VPF data structure

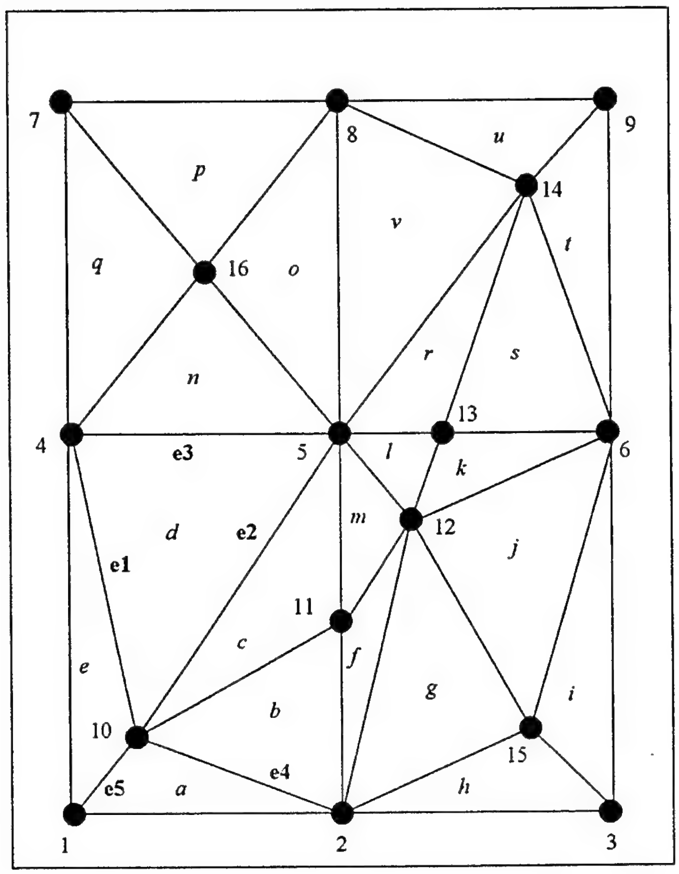
Advantages:

- Less storage than VPF (about three times less)
- Data format similar to that of ARC/INFO

Disadvantages:

- Will require substantial changes to VPF
- No edge table (but line features can easily be expressed in terms of a list of pointers to TIN vertices)

Vertex-Based Data Structure



Coordinates:

ID	x	y	z	Neighbors
1	x_1	y_1	z_1	2 10 4
2	x_2	y_2	z_2	3 15 12 11 10 1
. . .	. . .	. . .	. . .	. . .

Storage requirement = 10N - 2B - 6 storage units

Basic Queries:

- Point Location: about same complexity as triangle-based data structure
- Edge Neighbor finding: complex compared to triangle-based data structure
- Vertex Neighbor finding: simple

Advantages:

- Less storage than the triangle-based data format

Disadvantages:

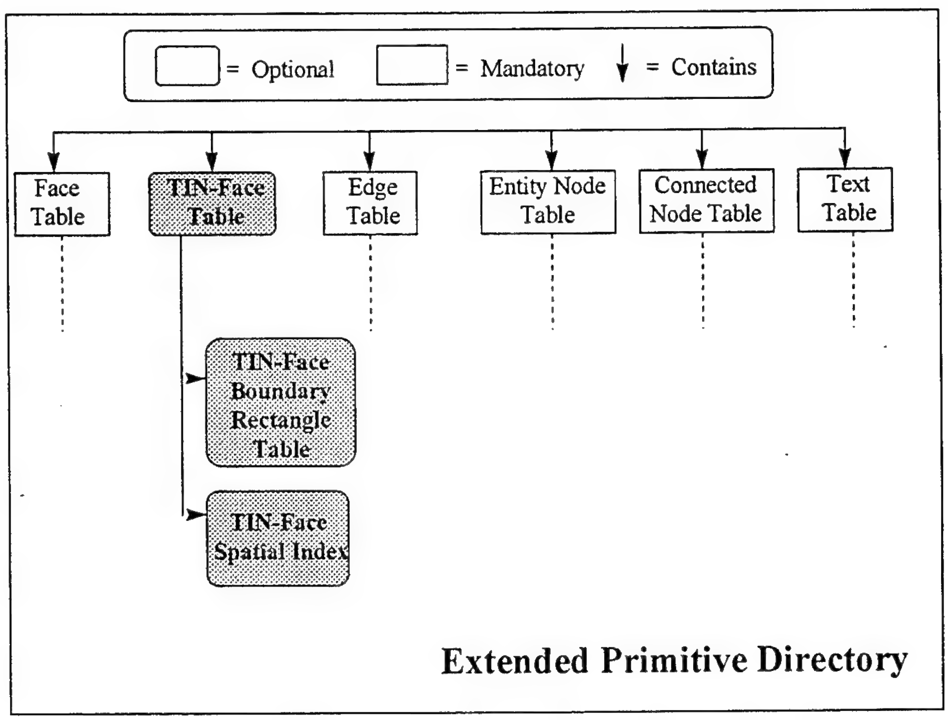
- Will require substantial changes to VPF
- Does not allow for area features
- Does not allow for line features

DATA STRUCTURE FOR TINs

Goal:

- Extend VPF to allow for the efficient storage of TIN-based elevation data
- Integrate terrain elevation data with ground surface features (point, line, and area features)

Methodology: Add an optional primitive TIN-face. A TIN-face will be stored using a triangle-based data structure



Structure of a TIN-Face Table

TIN-Face Table
Triangle Identifier
Vertex 1 Identifier
Vertex 2 Identifier
Vertex 3 Identifier
Adjacent Triangle 1 Identifier
Adjacent Triangle 2 Identifier
Adjacent Triangle 3 Identifier

HIERARCHICAL TINs

Hierarchical (multiresolution) TINs:

- Describe a terrain model at different levels of resolution.

- Each level corresponds to a particular surface elevation error. The root level is composed of all the TIN-triangles needed to reconstruct the surface with the largest error (the lowest level of resolution). The next level in the hierarchy contains TIN-triangles that when added to those of the root level yield a surface representation that has a higher resolution than that of the root level. Therefore, each level provides additional TIN-triangles that when combined with the existing ones bring the resolution of the surface to that of the corresponding level.

- Enables the compression of elevation data according to an accuracy level criterion.

- Features can be manipulated at different levels of accuracy.

Algorithms for the Generation of Hierarchical TINs:

Algorithms for the generation of hierarchical TINs can be classified into two broad categories:

- Recursive subdivision of enclosing triangles

  Ternary triangulation
  + simple
  - may lead to triangles with elongated shape (result in inaccuracies in numerical interpolation)

  Quaternary triangulation
  + avoids the generation of elongated triangles
  - may lead to discontinuous surfaces

  Cartographic coherence preservation
  + preserves cartographic coherence (features - such as ridges - of the surface to be approximated are preserved)
  - complex algorithm

- Retriangulation of the added points and their region of influence
  + avoids the generation of elongated triangles
  - complex

Data Structures for Hierarchical TINs:

All hierarchical TIN implementations can use essentially the same data structures.

Level Table

Level Table
Level ID
Max Error
Num. Triangle
Num. Points
Triangle List

Triangle Table

Triangle Table		
ID		
Max Error		
Type (internal, external, boundary)		
child list		
Internal	External	Boundary
Vertex 1 Vertex 2 Vertex 3 Adjacent 1 Adjacent 2 Adjacent 3	Parent Pointer	Adjacent 1 Adjacent 2 Adjacent 3

Appendix C. Feature Classes and Features.

1. AERONAUTICAL INFORMATION

Air Routes

GA005	Airspace
GA010	ATS Route Segment/Leg
GA015	Special Use Airspace
GA020	Airspace Boundary Sector
GA025	Special Use Airspace Segment
GA030	Off Route Radial/Bearing
GA035	NAVAIDS (Aeronautical)
GA045	Route (Air)
GA055	Waypoint/Reporting-Calling in Point
ZD020	Void Collection Area

2. BEACH

BA050	Beach
ZD020	Void Collection Area

3. DATA QUALITY

ZD020	Void Collection Area

4. DEMARCATION

Boundaries/Limits/Zones (Topographic)

FA000	Administrative Boundary
FA001	Administrative Area
FA005	Access Zone
FA015	Firing Range/Gunnery Range
FA020	Armistice Line
FA030	Cease-Fire Line
FA040	Claim Line
*FA041	Contact Zone
FA050	Mandate Line/Convention Line
FA060	Defacto Boundary
FA070	Demilitarized Zone
FA090	Geophysical Prospecting Grid
FA110	International Date Line
FA165	Training Area
FA170	Zone of Occupation

Boundaries/Limits/Zones (Hydrographic)

FC021	Maritime Limit Boundary
FC031	Maritime Area

*FC035 Pond Partition
FC036 Restricted Area
FC040 Traffic Separation Scheme System
*FC041 Traffic Separation Scheme (TSS)
FC100 Measured Distance Line
FC130 Radar Reference Line
FC165 Route (Maritime)
*FC166 Deep Water Route
*FC167 Defined Water
*FC168 Canal Route
FC170 Safety Fairway
*FC177 Swept Area

Miscellaneous

AL025 Cairn
AL070 Fence
AL260 Wall
ZD020 Void Collection Area

Other

_____ Sensitivity Areas
_____ Low Intensity Conflict Areas
_____ Key Tracking Areas

5. ELEVATION

CA010 Contour Line (Land)
CA020 Ridge Line
CA025 Valley Bottom Line
CA026 Breakline *(useful in TIN generation)*
CA030 Spot Elevation
CA035 Inland Water Elevation
CA040 Contour Polygon (Land) *(probable attribution: irregular triangle for TIN)*

Other

SA050 Slope Polygon
ZD020 Void Collection Area
_____ Berm/Barricade

6. HYDROGRAPHY

Coastal Hydrography

BA010 Coastline/Shoreline
BA020 Foreshore
BA030 Island
BA040 Water (Except Inland)
*BA051 Dyke Crown
_____ Surf

Ports and Harbors

BB005	Harbor
*BB006	Harbor Complex
*BB007	Channel Edge
BB010	Anchorage
*BB012	Anchor Berth
BB019	Anchor
BB020	Berth
*BB021	Mooring Trot
BB022	Basin
*BB030	Bollard
BB040	Breakwater/Groyne
*BB042	Mole
BB050	Calling-In Point
BB079	Mooring/Warping Facility
BB080	Dolphin
BB081	Shoreline Construction
BB090	Drydock
*BB100	Fish Stakes
BB105	Fishing Harbor
BB110	Fish Traps/Fish Weirs
BB111	Tunny (Tuna) Nets Area
BB115	Gridiron
BB140	Jetty
BB150	Landing Place
BB151	Landing Stairs
BB160	Mooring Ring
BB170	Offshore Loading Facility
*BB180	Oyster Bed/Mussel Bed
BB190	Pier/Wharf/Quay
BB199	Floating Dock
BB200	Pump Out Facility
BB201	Small Craft Facility
BB220	Ramp (Maritime)
BB230	Seawall
BB240	Slipway/Patent Slip
BB250	Watering Place
SU003	Port Facility

NAVAIDs

BC010	Beacon
BC020	Buoy
BC030	Leading Light(s)
BC031	Navigation Line
BC032	Radar Line
BC033	Radar Range

BC035	Lights in Line
BC040	Light
BC050	Lighthouse
BC055	Marker
BC060	Light Sector
BC070	Light Vessel/Lightship
BC080	Perches/Stakes
BC100	Leading Line
BC101	Fog Signal

Dangers/Hazards

BD000	Underwater-Danger/Hazard
BD001	Mine
BD005	Miscellaneous Underwater Feature
BD010	Breakers
BD020	Crib
BD030	Discolored Water
BD040	Eddies
BD050	Foul Ground
BD060	Kelp/Seaweed
BD070	Obstruction (Nautical)
BD071	Log Boom/Booming Ground
BD072	Pontoon
BD073	Oil Barrier
BD074	Chain/Wire
BD079	Fishing Facility
BD080	Overfalls/Tide Rips
BD100	Pile/Piling/Post
BD110	Platform
BD111	Offshore Platform Site (cleared)
BD112	Production Installation
BD119	Ledge
BD120	Reef
*BD121	Pingo
BD130	Rock
BD140	Snags/Stumps
BD180	Wreck
BD181	Hulk
_____	Spoil/Disposal Area
_____	Mine-Like Objects
_____	Seamount

Depth Information

BE010	Depth Curve
BE015	Depth Contour
*BE019	Depth Area
BE020	Sounding

BE021	Drying Line, Low Water Line-LWL
BE022	Sand Line
BE023	Mud Line
BE029	Bottom Return
BE030	Track Swath
BE040	Track Line

Bottom Features

BF010	Bottom Characteristics
BF011	Bottom Feature
_____	Bottom Type (acoustic)
_____	False Acoustic Targets
_____	Underwater Canyon
_____	Shelf

Tide and Current Information

BG010	Current Flow
BG011	Tideway
BG012	Water Turbulence
BG020	Tide Gauge
BG030	Tide Data Point
BG040	Current Diagram
_____	Sound Speed Profiles

Inland Water

BH000	Inland Water
BH010	Aqueduct
BH015	Bog
BH020	Canal
BH030	Ditch
BH040	Filtration Beds/Aeration Beds
BH050	Fish Hatchery/Fish Farm/Marine Farm
BH060	Flume
BH070	Ford
BH075	Fountain
BH077	Hummock
BH080	Lake/Pond
BH090	Land Subject to Inundation
*BH091	Flooded Area
BH095	Marsh/Swamp
BH100	Moat
BH110	Penstock
*BH115	Underground Water/Phreatic Water
BH120	Rapids
BH130	Reservoir
BH135	Rice Field
BH140	River/Stream
BH141	River Bank

BH145 River Stream Vanishing Point
BH150 Salt Pan
BH155 Salt Evaporator
BH160 Sebkha
BH165 Spillway
BH170 Spring/Water-Hole
BH175 Trough
BH180 Waterfall
BH190 Lagoon/Reef Pool
BH200 Miscellaneous Surface Drainage Feature
BH210 Inland Shoreline
BH501 River Navigation Route

Miscellaneous Inland Water

BI005 Boat Lift
BI010 Cistern
BI020 Dam/Weir
BI030 Lock
*BI039 Sluice
BI040 Sluice gate
BI041 Gate (Nautical)
BI042 Caisson
BI043 Flood Barrage
BI050 Water Intake Tower
*BI060 Fish Ladder
BI070 Gauging Station

Snow/Ice

BJ020 Moraine
BJ030 Glacier
BJ040 Ice Cliff
BJ060 Ice Peak/Nunatak
BJ065 Ice Shelf
BJ070 Pack Ice
BJ080 Polar Ice
BJ100 Snow Field/Ice Field
BJ110 Tundra

Other

ZD020 Void Collection Area
SA010 Common Open Water
SA060 Covered Drainage

7. INDUSTRY

Extraction

AA010 Mine
AA011 Quarry/Mine Shear Wall

AA012 Quarry
AA013 Pit
AA040 Rig/Superstructure
AA050 Well
AA051 Wellhead
AA052 Oil/Gas Field

Disposal

AB000 Disposal Site/Waste Pile
AB010 Wrecking Yard/Scrap Yard
*AB020 Burner
*AB021 Diffuser

Processing Industry

AC000 Processing Plant/Treatment Plant
AC010 Blast Furnace
AC020 Catalytic Cracker
AC030 Settling Basin/Sludge Pond
AC040 Oil/Gas Facilities
AC050 Works

Associated Industrial Structures

AF010 Chimney/Smokestack
AF020 Conveyor
AF030 Cooling Tower
AF040 Crane
*AF041 Sheerlegs (Shear Legs)
AF050 Dredge/Powershovel/Dragline
AF060 Engine Test Cell
AF070 Flare Pipe
AF080 Hopper

Agriculture

AJ010 Circular Irrigation System
*AJ020 Siphon
AJ030 Feed Lot/Stockyard/Holding Pen
AJ050 Windmill
*AJ051 Windmotor

Miscellaneous

AL140 Particle Accelerator
AL240 Tower (Non-Communication)
AL241 Tower (General)

Storage

AM010 Depot (Storage)
AM020 Grain Bin/Silo
AM030 Grain Elevator
AM060 Storage Bunker/Storage Mound
AM070 Tank
AM080 Water Tower

*AM031	Timber Yard
*AM040	Mineral Pile

Other

ZD020	Void Collection Area

8. PHYSICAL GEOGRAPHY

Exposed Surface Materials

DA005	Asphalt Lake
*DA006	Alkali Flats
DA010	Ground Surface Element
DA020	Barren Ground
*DA030	Land Area
*DA031	Land Region
SA020	Disturbed Soil
SA030	Exposed Bedrock

Landforms

DB010	Bluff/Cliff/Escarpment
DB030	Cave
DB031	Hill
DB060	Crevice/Crevasse
DB070	Cut
DB080	Depression
DB090	Embankment/Fill
DB100	Esker
DB110	Fault
DB115	Geothermal Feature
DB145	Miscellaneous Obstacle
DB150	Mountain Pass
DB160	Rock Strata/Rock Formation
DB170	Sand Dune/Sand Hills
DB176	Slope Category
DB180	Volcano
DB190	Volcanic Dike
DB200	Gully/Gorge
DB210	Potential Landslide Area
*DB211	Landslide
DB230	Fan
DB240	Karst
DB500	Bottomline of Cliff
DB501	Topline of Cliff

Other

ZD020	Void Collection Area
SA040	Permanent Snowfield

9. POPULATION

Institutional/Government

AH010 Bastion/Rampart/Fortification
AH020 Trench
AH050 Fortification
AH060 Underground Bunker
AH070 Checkpoint
SU001 Military Base

Residential

AI020 Mobile Home/Mobile Home Park
AI030 Camp

Recreational

AK020 Amusement Park Attraction
AK030 Amusement Park
AK040 Athletic Field
AK050 Tennis Court(s)
AK060 Campground/Campsite
*AK061 Picnic Site
*AK070 Drive-In Theater
*AK080 Drive-In Theater Screen
AK090 Fairground
AK091 Exhibition Grounds
AK100 Golf Course
*AK101 Golf Driving Range
AK110 Grandstand
AK120 Park
*AK121 Lookout
AK130 Race Track
AK150 Ski Jump
AK155 Ski Track
AK160 Stadium/Amphitheater
AK170 Swimming Pool
AK180 Zoo/Safari Park

Miscellaneous

*AL005 Animal Sanctuary
AL012 Archeological Site
AL015 Building
AL018 Building Superstructure Addition
AL019 Shed
AL020 Built-Up Area
AL030 Cemetery
*AL040 Cliff Dwelling
AL045 Complex Outline
AL050 Display Sign

AL073 Flagstaff/Flagpole
*AL075 Gallery
*AL080 Gantry
*AL090 Grave Marker
AL100 Hut
AL101 Cabin
AL105 Settlement
*AL110 Light Standard/Light Support
*AL116 Calvary Cross
AL130 Monument
AL135 Native Settlement
*AL141 Telescope
*AL155 Overhead Obstruction Location
AL170 Plaza/City Square
AL120 Missile Site
*AL195 Ramp
AL200 Ruins
AL201 Historic Site/Point of Interest
AL220 Steeple
*AL250 Underground Dwelling

Other

ZD020 Void Collection Area

10. TRANSPORTATION

Miscellaneous

AL060 Dragon Teeth
AL210 Snow Shed/Rock Shed

Railroad

AN010 Railroad
AN050 Railroad Siding/Railroad Spur
AN060 Railroad Yard/Marshalling Yard
AN075 Railroad Turntable
AT100 Electrified Railroad Pylon

Road

AP010 Cart Track
AP020 Interchange
AP030 Road
AP040 Gate
AP041 Barrier
AP050 Trail
*AP060 Drove

Associated Transportation

AQ010 Aerial Cableway Lines/Ski Lift Lines
AQ020 Aerial Cableway Pylon/Ski Pylon

*AQ021	Mast
AQ030	Boardwalk
AQ040	Bridge/Overpass/Viaduct
AQ045	Bridge Span
AQ050	Bridge Superstructure
AQ055	Bridge Tower/Bridge Pylon
AQ056	Bridge Pier
AQ058	Constriction/Expansion
AQ060	Control Tower
AQ062	Crossing
AQ064	Causeway
AQ065	Culvert
AQ070	Ferry Crossing
AQ080	Ferry Site
AQ090	Entrance/Exit
AQ100	Landmark Post/Distance Post
AQ110	Mooring Mast
AQ111	Prepared Raft or Float Bridge Site
AQ113	Pipeline/Pipe
AQ116	Pumping Station
AQ118	Sharp Curve(s)
AQ120	Steep Grade
AQ125	Station (Miscellaneous)
AQ130	Tunnel
AQ135	Vehicle Stopping Area/Rest Area
AQ140	Vehicle Storage/Parking Area
AQ150	Flight of Steps

Aerodrome

GB005	Airport/Airfield
GB006	Airfield
*GB007	Airport Area
GB010	Airport Lighting
GB015	Apron/Hardstand
GB020	Arresting Gear
GB025	Blast Barrier
GB030	Helicopter Landing Pad
GB035	Heliport
GB040	Launch Pad
GB045	Overrun/Stopway
GB050	Revetment (Airfield)
GB055	Runway
GB057	Shoulder
GB060	Runway Radar Reflector
GB065	Seaplane Base
GB070	Seaplane Landing/Seaplane Take-Off Area

GB075 Taxiway
GB080 Wind Indicator
GB160 Decontamination Pad
GB170 INS Alignment Pad
GB220 Air Obstruction
GB221 Miscellaneous Air Obstruction

Other

SU002 Subway
ZD020 Void Collection Area
_____ Route/Distance Marker
_____ Fueling Areas

11. UTILITY

Power Generation

AD010 Power Plant
AD020 Solar Panels
AD030 Substation/Transformer Yard
AD040 Nuclear Reactor

Communications/Transmission

AT005 Cable
AT010 Disk/Dish
AT020 Early Warning Radar Site
AT030 Power Transmission Line
AT040 Power Transmission Pylon/Line
AT041 Telpher
AT045 Radar Transmitter
AT050 Communication Building
AT060 Telephone Line/Telegraph Line
AT070 Telephone-Telegraph Pylon/Pole
AT080 Communication Tower
_____ Telephone Station
_____ Communication Nodes
_____ Poles

Other

ZD020 Void Collection Area
_____ Condensation Line
_____ Steam Line

12. VEGETATION

Cropland

EA010 Cropland
EA020 Hedgerow
EA030 Nursery
EA031 Botanical Garden

EA040	Orchard/Plantation
EA050	Vineyards
EA055	Hops

Rangeland

EB010	Grassland
EB015	Grass/Scrub/Brush
EB020	Scrub/Brush
EB030	Land Use/Land Cover (Vegetation)

Woodland

EC010	Bamboo/Cane
EC015	Forest
EC020	Oasis
EC030	Trees
EC040	Cleared Way/Cut Line/Firebreak

Wetland

_____	Wetlands

Miscellaneous Features

EE000	Miscellaneous Vegetation

Other

ZD020	Void Collection Area

Some general features which may also be included in one or more of the above are as follows:

Control Points

ZB020	Benchmark
ZB030	Boundary Monument
ZB035	Control Point/Control Station
ZB036	Distance Mark
ZB040	Diagnostic Point
ZB060	Geodetic Point

Magnetic Variation

ZC040	Magnetic Disturbance Area
ZC050	Isogonic Lines
ZC051	Magnetic Pole

Miscellaneous

ZD001	Network
ZD003	Artifact Location
ZD012	Geographic Information Point
ZD015	Point of Change
ZD020	Void Collection Area
ZD040	Named Location
ZD045	Text Description